Case Report

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Quick Brain MRI in a Tertiary Pediatric Emergency Department: A Retrospective Study on Use Patterns and Accuracy

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Abstract

In this report, we describe a 2-year-old female who played with magnetic beads and swallowed five of them. Four were in the stomach and one was in the colon when the parents found the girl swallowed the beads. Four beads in stomach were removed endoscopically. The one in the colon was not discovered in subsequent colonoscopy because of poor bowel preparation. The patient was observed for seven days during which the patient was well without any abdomen symptom, but the magnetic bead remained in the colon, as seen in the abdominal X-ray and computed tomography. We repeated the colonoscopy and found the foreign body stuck to the mucosa which endoscopically did not show any obvious abnormality. We then performed endoscopic submucosal dissection with an IT-Knife, took out the bead, and closed the incision with clips, thereby avoiding open surgery. We advise that parents should pay more attentions to small children who may ingest foreign bodies inadvertently. We conclude that the endoscopic procedures are effective in removing swallowed foreign bodies.

Keywords: Foreign body; Colon; Endoscope; Endoscopic Submucosal Dissection (ESD)

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Introduction

Emergency department (ED) physicians must frequently decide between neuroimaging modalities for a wide range of clinical complaints including ventriculoperitoneal (VP) shunt malfunction, trauma, stroke, headache, and seizure. The benefits of neuroimaging versus the risk of radiation exposure from computed tomography (CT) scans or potential exposure to anesthesia for full sedated magnetic resonance imaging (MRI) must be carefully considered.

CT imaging of the head is used frequently for pediatric patients. Although a recent study examining two pediatric ED sites showed a decline in head CT use, CT imaging of some type was still performed during 5.5% of over 50,000 pediatric ED visits, with 63% of these studies including a head CT [1]. A 2018 study demonstrated that of 4.5 million children in the Nationwide Emergency Department Sample (NEDS) database presenting with traumatic brain injury, 26% underwent a head CT [2].

While the use of pediatric-specific CT parameters has substantially decreased overall radiation exposure and cancer risk estimates with CT use have varied widely, the literature does suggest at least a small increased lifetime cancer risk associated with CT exposure and there is consensus that medical providers should seek strategies to decrease radiation exposure when possible [3].An Australian pediatric study evaluating a database of 11 million patients demonstrated an overall increased incidence of cancer, which was greatest in children with CT exposure prior to 5 years of age [4]. The risk is most prominent in children who are exposed to repeated head CT, which is common in children with shunted hydrocephalus or other conditions that require serial examination [5, 6–11].As such, the use of radiation-free imaging modalities including MRI should be considered when possible.

The introduction of QuickBrain MRI (qbMRI) in 2002 represents an advancement in neuroimaging, using T2-weighted fast spin-echo images to create thicker slides that can be obtained within minutes and often without sedation [12,13]. Additional sequences including diffusion-weighted imaging (DWI) and gradient-recalled echo (GRE) can now be added to provide additional information, with an estimated 30 seconds to 2 minutes added per additional sequence [14,15]. Previous retrospective studies have compared the use of qbMRI and CT for VP shunt evaluation, and have demonstrated qbMRI as a reliable modality for shunt evaluation [16–18]. For some institutions, this has led to the modification of clinical pathways preferring the use of qbMRI over CT as the first-line assessment for suspected shunt malfunction [19].

Many pediatric centers are investigating the expansion of qbMRI use beyond shunt-related indications. Within the trauma setting, there is emerging evidence suggesting qbMRI could be a viable alternative to CT imaging. In a retrospective study comparing qbMRI and CT imaging in pediatric trauma, Sheridan, et al., demonstrated 100% sensitivity for detecting clinically significant traumatic brain injury [20].A similarly powered retrospective study at a tertiary pediatric ED found that no clinically significant intracranial injuries were known to be missed within the qbMRI group. Additionally, a small retrospective study demonstrated that qbMRI with DWI was more sensitive than CT for detecting ischemia in pediatric arterial ischemic stroke. This combination of promising test characteristics and absence of radiation-induced cancer risk makes qbMRI a very attractive neuroimaging modality for pediatric patients.

There remains little literature on the effectiveness of qbMRI in pediatric patients beyond trauma and shunted hydrocephalus. A 2008 retrospective study of both pediatric and adult patients demonstrated an increase in use of qbMRI for non-hydrocephalic indications. This study, however, mostly involved single qbMRI images from patients presenting with macrocephaly, providing very limited information about qbMRI accuracy [21]. A 2013 retrospective review of pediatric patients undergoing urgent evaluation for indications other than hydrocephalus identified limitations in qbMRI to identify venous sinus thrombosis and associated venous hemorrhage. However, the small number of patients and confounding presence of hydrocephalus (30 patients, 40% with indication of VP shunt insertion or revision/follow-up) makes this difficult to generalize.

The primary objective of this retrospective study was to review the use of qbMRI for non-shunt non-hydrocephalic indications within a single tertiary pediatric ED. Additionally; we aimed to compare qbMRI results to any standard neuroimaging obtained. This serves as an important study to describe not only the experience at a single institution, but also create a foundation for future qbMRI research in pediatric medicine.

Methods

This retrospective study was approved by the Institutional Review Board and is a medical records and imaging studies review of pediatric patients (age 0-18 years), who were seen at a single tertiary pediatric ED between January 2010 and June 2017 and who underwent qbMRI. Patients were excluded if they had a VP shunt at the time of imaging or if their principal chief complaint was an established diagnosis of hydrocephalus. The remaining patients had qbMRI obtained for non-shunt indications at the discretion of the attending at the time of the original ED encounter. Trauma patients most commonly underwent a qbMRI after having an initial CT scan performed at an outside facility. There is no current protocol for the use of qbMRI at this institution except in the evaluation of patients with VP shunts.

Information gathered from the electronic medical record included date of birth, date of ED visit, gender, ethnic group, presenting complaint, principal final diagnosis, and ED disposition. The presenting complaint and principal final diagnosis were adjusted to reflect the most relevant clinical indication for imaging and/or hospital admission. For example, if the patient's chief complaint was "multiple issues" including a seizure, seizure was listed as the presenting study complaint. Similarly, if a patient was admitted for seizures but the principal final diagnosis was listed as "fever" with a secondary diagnosis of seizures, seizures was listed as the disposition diagnosis. We also recorded the following: whether patients received anxiolytic medications (midazolam or lorazepam) within 30 minutes of qbMRI, time between MRI order and imaging start time, and use of standard MRI or CT neuroimaging during the same ED encounter or standard MRI neuroimaging at a subsequent hospital encounter. All trauma patients had CT neuroimaging within the same encounter or just prior to transfer to our institution. For some patients with known lesions, neuroimaging at a subsequent hospital encounter was used within 3 months of the index visit.

When CT images were available for comparison, most had been obtained prior to the qbMRI to evaluate any neurotrauma. If standard MR images were obtained this occurred after the qbMRI for further evaluation or to follow known lesions, either at the same encounter or during a subsequent encounter. Only imaging studies available for direct review by the study center radiologists were included. Additional neuroimaging obtained after a neurological procedure was not included. The type of additional neuroimaging was recorded as CT imaging, standard MRI without contrast, or standard MRI with and without contrast. The inclusion and exclusion process and imaging classification are outlined in **(Figure 1)**.

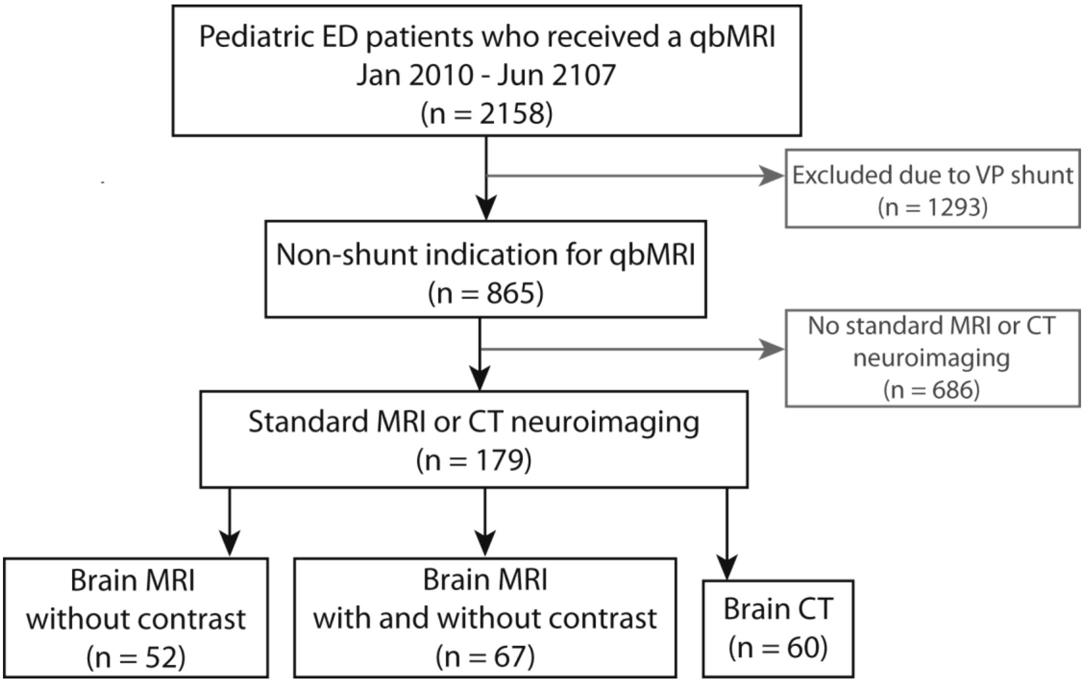

Figure 1. Retrospective qbMRI study inclusion and exclusion criteria.

Neuroimaging results were determined based on the final interpretation of the neuroradiology attending physician. For image sets with discordant results, the differences in findings were also recorded. Test characteristics including sensitivity, specificity, positive predictive value, and negative predictive value were calculated for qbMRI across non-shunt indications.

Results

A total of 865 patient records (mean age 6.45 years) met the inclusion criteria and were reviewed and 179 (21%) underwent standard MRI or CT neuroimaging. Of the 865 qbMRI studies, 3.5% had additional sequences added according to provider discretion; 15 with DWI, 13 with GRE, and 2 with both DWI and GRE sequences. Of the 865 patients, 514 patients (59%) were male and 351 (41%) were female, 719 (85%) identified as non-Hispanic, 132 (15%) identified as Hispanic, and 14 (1.6%) were unknown. A total of 287 patients (33%) were admitted to the hospital and 578 (67%) were discharged home. The average time from qbMRI order placement until the patient's imaging start time was 29.5 minutes. A total of 59 patients (6.8%) received an anxiolytic medication (either lorazepam or midazolam) within 30 minutes prior to qbMRI. Of those patients who received lorazepam or midazolam, 7 (<1%) were given this medication solely for seizure rescue rather than for anxiolysis to obtain a qbMRI.

The most common presenting complaints were headache (17%), seizure (15%), vomiting/nausea (12%), fall or head injury (10%), and altered mental status that included lethargy, confusion, or aggressive behavior (10%). The most common final diagnoses were seizure (16%), headache (15%), trauma requiring admission (9%), concussion or closed head injury (9%), and other (18%) **(Table 1)**.

Presenting complaint or final diagnosis	**Patients with this as presenting complaint, n (%)**	**Patients with this as ED disposition diagnosis, n (%)**
Headache	150 (17)	134 (15)
Seizure, concern for seizure	131 (15)	140 (16)
Vomiting or nausea	101 (12)	65 (8)
Infectious such as gastroenteritis, pneumonia, urinary tract infection, meningitis		65 (8)
Fall/ head injury or concussion not requiring admission	88 (10)	79 (9)
AMS such as lethargy, confusion, aggressive behavior	82 (10)	47 (5)
Trauma system activation or trauma system activation requiring admission	79 (9)	82 (9)
Focal neurologic deficit including ataxia	48 (6)	25 (3)
Infant concerns[1]	39 (5)	46 (5)
Post-op complaint[2]	37 (4)	32 (4)
Other	110 (13)	152 (18)

[1]fussiness, crying, bulging fontanel, increasing head circumference, head swelling in an infant
[2]wound check/concern, CSF leak, pain

Table 1: Presenting complaints and final diagnoses

The results of 469 qbMRI studies were normal (54%). Of the patients who presented with a headache, 76 (57%) had a normal qbMRI and 24 (18%) had stable previously known findings. There were no new, non-traumatic findings, or findings that prompted hospital admission. Of the patients who presented with a seizure, 105 (75%) had a normal qbMRI. Two patients (1%) had a new, non-traumatic finding, and 1 patient had a known post-operative finding and required hospital admission. An additional 12% of patients had stable previously known abnormalities. A further 7% had intracranial hemorrhage with or without skull fracture **(Table 2).**

Findings	**Patients, n (%)**
normal	469 (54)
intracranial hemorrhage (with or without skull fracture)	63 (7)
skull fracture without hemorrhage	15 (2)
mass lesion	19 (2)
hydrocephalus/ventriculomegaly	49 (6)
cyst (arachnoid, pineal)	30 (4)
sinusitis	30 (4)
Stable or expected post-operative changes **or** other known abnormalities.	105 (12)
New subdural fluid, hygroma, extra-axial fluid collections **not** related to trauma	14 (2)
post-op or other **known** findings, patient was admitted	10 (1)
Cephalohematoma, scalp hematoma or soft tissue swelling	17 (2)
other (including inflammatory lesion, structural vascular malformation, cerebral edema, cerebral infarct)	44 (5)

Table 2: qbMRI findings in all patients

Of the patients who received additional neuroimaging, 60 (7%) underwent CT upon arrival or prior to arrival to the ED. Fifty-two patients (6%) underwent standard MRI without contrast and 67 patients (8%) underwent standard MRI with and without contrast. When considering all patients who had additional neuroimaging, 50 (28%) had a normal qbMRI and 42 (23%) had a qbMRI demonstrating intracranial hemorrhage **(Table 3).**

	N (%)
Normal	51 (28)
Intracranial bleed	42 (23)
Skull fracture without bleed	10 (6)
Mass lesion	13 (7)
Hydrocephalus	5 (3)
Cyst	5 (3)
Vascular malformation	2 (1)
Cerebral infarct	2 (1)
Sinusitis	3 (2)
Known findings, stable	16 (9)
New finding	5 (3)
Known findings, patient was admitted	2 (1)
Soft tissue finding	4 (2)
Other	19 (11)

Table 3: qbMRI findings in patients who also underwent CT or standard MR Neuroimaging

The sensitivity and specificity of qbMRI to detect any abnormality compared to CT or standard MRI neuroimaging were 91% and 97%, respectively. The positive predictive value of qbMRI was 99% and the negative predictive value was 73%. There were 13 patients with false negative results and 1 patient with false positive results. Their diagnoses, findings, and clinical correlation are detailed in Table 4.

Patient no.	Age; sex (male/female)	Presentation	qbMRI type	qbMRI false positive or false negative	qbMRI Findings	qbMRI Limitations	Clinical Correlation
1	9 years; male	Trauma	qbMRI only	negative	Normal	CT showed small focus of extra-axial or cortical hyperdensity	Patient monitored overnight in PICU without further imaging and discharged home
2	5 years; male	Trauma	qbMRI only	negative	Normal except for subgaleal soft tissue swelling	CT showed non-displaced right occipital fracture without hemorrhage	Patient monitored in the PICU without further imaging and discharged home
3	3 years; male	Trauma	qbMRI only	negative	Normal except for left temporal soft tissue swelling	CT showed non-displaced left temporal bone fracture and non-displaced right frontal bone fracture	Patient admitted and monitored without further neuroimaging and discharged home
4	2months; female	Trauma	qbMRI only	negative	Normal	CT showed small areas of hyperdensity within right frontal and left frontoparietal lobe, representing subarachnoid vs subdural hemorrhage	Patient admitted and monitored without further neuroimaging and discharged home
5	8months; female	Trauma	qbMRI only	negative	Normal	CT showed non-depressed (vs mildly depressed) left parietal skull fracture	Patient admitted and monitored without further imaging and discharged home
6	4 weeks; male	Trauma	qbMRI only	negative	Normal except for soft tissue swelling over left	CT showed subarachnoid and subdur	Patient admitted and monitored without

					scalp	al hemorrhages with bilateral parietal skull fractures	further neuroimaging and discharged home
7	9months; male	Trauma	qbMRI with GRE	negative	Normal	CT showed non-depressed bilateral occipital fractures	Patient admitted and monitored without further neuroimaging and discharged home
8	5 weeks; female	Seizure	qbMRI only	negative	Normal	MRI wwo contrast, DWI sequence demonstrating focal diffusion restriction in the left parietal lobe as well as some scattered foci of diffusion restriction located in the left frontal lobe	Patient admitted for ongoing seizure activity and full MRI ordered as part of further work-up. Discharged home on levetriacetamand aspirin with stroke clinic follow-up

						and right posterior or frontal/parietal. Imaging consistent with multifocal thromboembolic strokes	
9	2 years; female	Eye deviation and papilledema	qbMRI only	negative	Normal	MRI + orbit wwo contrast showing 5mm right orbital coloboma	Ophthalmology and neurosurgery evaluations in ED, discharged from ED with plan to follow-up with ophthalmology
10	11 days; female	Seizures	qbMRI only	negative	Normal	MRI wwo contrast showing multiple foci of intrinsic T1 hyperintensity and diffusion restriction in	Patient admitted for ongoing seizure activity and full MRI ordered as part of further work-up. Findings thought to be possibly

						the periventricular white matter of the frontal and parietal hemispheres bilaterally and symmetrically	secondary to hypoxic event at birth. Discharged home on levetiracetam with neurology follow-up
11	3 years; male	Weakness and ataxia	qbMRI only	negative	Normal	MRI wwo contrast showing Symmetric abnormal increased T2/flair signal with restricted diffusion in the bilateral globi pallidi	Patient admitted for persistently abnormal neurologic examination, full MRI ordered as part of further work-up. Concern for underlying metabolic process. Discharged to inpatient rehabilitation.
12	2 months; male	Seizure	qbMRI only	negative	Normal	MRI wo contrast showing several small foci of subependymal gray matter heterotopia lining the ventricles. Also had an initial head CT showing hypodensity within temporal lobe thought to be artifact	Patient admitted for ongoing seizure activity and full MRI ordered as part of further work-up. Findings of band heterotopia a disorder of neuronal/cortical migration. Discharged home on levetiracetam with neurology follow-up
13	5 years; male	Acute painless vision loss	qbMRI only	negative	Normal	MRI wo contrast + MRA showing possible focal narrowing of internal carotid artery, though follow-up CTA was negative	Patient admitted for further work-up. Found to have central retinal artery occlusion by ophthalmology examination only. Patient was dischar

							ged home on aspirin with plan for ophthalmology and stroke clinic follow-up
14	7 months; male	Increasing head circumference	qbMRI only	positive	Benign enlargement of subarachnoidspaces of infancy plus possiblesubdural fluid overlying bilateral cerebral convexities	MRI wo contrast showing minimally prominent subarachnoid spaces but otherwise normal	Observed in the emergency department, evaluated by neurosurgery, and discharged home once full MRI completed

Table 4: Clinical and Imaging findings in patients with qbMRI findings incongruent with CT or standard MRI neuroimaging

Of the 13 false negative qbMRI results, 7 occurred in trauma patients who had additional findings identified on CT imaging. Four of these trauma patients had non-depressed skull fractures and 3 had small hyper dense areas of subarachnoid or subdural hemorrhage that were not clearly evident on subsequent qbMRI. It is unclear if these small CT hyper densities resolved prior to qbMRI or were not observed. All 3 of the patients with areas of hemorrhage were admitted for observation and subsequently discharged without any further neuroimaging or intervention required. None of the 7 trauma patients had a CT or standard MRI finding that altered clinical management or discharge timing.

The 6 non-trauma patients with false negative qbMRI results presented with variable diagnoses. One case had follow-up imaging in the ED and was subsequently discharged home. In the remaining 5 non-trauma cases, patients were admitted from the ED for ongoing clinical concern and had follow-up imaging during their admission. Their hospital courses are further detailed in Table 4. Three patients were admitted for seizures and had alterations to their clinical management instituted after CT or standard MR imaging. One patient was admitted for a persistently abnormal neurologic examination and had MRI findings concerning for a metabolic process before discharging to inpatient rehabilitation. One patient was admitted for acute vision loss and was ultimately diagnosed with central retinal artery occlusion after ophthalmologic consultation.

There was 1 false positive qbMRI that raised concern for possible subdural hygromas overlying the cerebral convexities. Follow-up standard MRI revealed only benign enlargement of the subarachnoid spaces of infancy. This benign finding did not require intervention or change to follow-up planIT-Knife to dissected the submucosa in order to avoid damage to the nearby tissue. At last the bead was retrieved and the procedure lasted for about 55 minutes.

Discussion

The endoscope was used for diagnosis and subsequent removal of these foreign bodies, and if employed optimally, it prevents complications and surgical removal may be avoided. The most important measure to prevent this important pediatric healthcare problem is proper parent education: children should be prevented from contacting small objects that could be swallowed, and in this particular case, small objects with magnetic properties should not be bought as toys and young children should not be allowed to play with them.

The use of qbMRI for evaluation of pediatric patients with suspected VP shunt failure is standard practice at many health centers. This study provides novel data from a single, high volume tertiary pediatric ED documenting extensive additional use of qbMRI for a wider range of diagnoses. In addition, the availability of contemporary CT or standard MR imaging in many of these patients allowed us to learn more about the test characteristics of qbMRI obtained in the ED setting for a broad array of non-shunt related presentations.

The present study results align with previous studies on qbMRI use within trauma settings, in that the most common finding not seen on qbMRI was non-depressed skull fracture, a diagnosis which carries very low risk for evolution requiring operative management or inpatient monitoring [22].In our study, neurotrauma patients with false negative findings on qbMRI did not require additional intervention or other change in clinical management based on their positive standard imaging findings. However, it is difficult to generalize this information as there are clinical scenarios, such as non-accidental trauma, where missed findings such as skull fractures would be extremely clinically significant.

In this study, qbMRI provided accurate diagnoses in a high proportion of patients presenting with non-traumatic and non-hydrocephalic presentations. There were no false negative qbMRI results in patients with positive findings on previous studies, suggesting that qbMRI may be particularly useful and reliable for follow-up imaging during a single extended clinical episode.

Current guidelines recommend against routine use of neuroimaging in the evaluation of common complaints including headache or seizure. The American Academy of Neurology (AAN) recommends imaging for recurrent headache only in the setting of worsening severity or change in headache type, abnormal neurologic examination, or in the presence of seizures [23]. The AAN does not recommend routine neuroimaging for the occurrence of a first-time, unprovoked seizure in children [24,25].In many clinical situations including status epilepticus or recurrent seizures of unknown etiology, the decision to obtain neuroimaging depends on clinical context and judgment. In such circumstances, qbMRI could serve as a viable initial screening tool to replace CT imaging.

Nevertheless, there remain a number of barriers to more widespread use of qbMRI for children in an ED setting. A 2014 survey of ED physicians

regarding imaging for pediatric traumatic brain injury documented physicians' concerns with qbMRI availability, patient tolerance of the narrower scanner confines, and time for MRI acquisition. However, other data suggest that patient tolerance of qbMRI is similar to CT imaging
given the short scanning time required, and that failure rates for obtaining qbMRI are similarly low.A recent department quality assurance review of our qbMRI department image acquisitions has shown the median time to directly acquire the qbMRI images was 4 minutes and 52 seconds (standard deviation: 1 minute and 58 seconds) compared to CT image acquisition that took a median of 2 minutes and 28 seconds (standard deviation: 1 minute and 54 seconds).This qbMRI acquisition time is certainly more comparable to CT image acquisition time than to standard MRI.
A need for anxiolytic medications is another potential barrier to qbMRI, although the present study documents a relatively low utilization of these medications. Similarly, previous data from Yue, et al., has demonstrated no significant difference in the rate of anxiolytic medication use while obtaining CT imaging or qbMRI in children (4.4% of cases). It is more difficult to assess the availability and ease of access for qbMRI across health care centers, though limited data has shown an increase in MRI utilization in tertiary pediatric emergency departments [27,28]. The present study demonstrated a time from ordering a qbMRI study to scan initiation as 29.5 minutes. This time represents a single center with 24-hour access to MRI scanner within the same emergency department. Acquisition time difference between CT and qbMRI has previously been evaluated for both neurotrauma and suspected VP shunt failure, showing slightly longer acquisition times for qbMRI, although for trauma patients this difference was largely attributable to longer time until placement of an order. It is likely that qbMRI acquisition times can be shortened through more standardized use of qbMRI as the default urgent brain imaging study for children at any given institution.

There are several study limitations. This study is limited by its retrospective nature and the lack of standard qbMRI protocol. It is further limited because a large number of patients (686) did not undergo either CT or standard MRI neuroimaging for comparison. For those patients with normal qbMRI findings who did not have any subsequent neuroimaging or follow-up, it is difficult to make a definitive
statement as to the utility of those qbMRI images. There was also heterogeneity in the indications for neuroimaging. QbMRI and CT imaging are subject to different types of imaging artifact. Thus, it may not be possible in any individual case to be certain whether a small finding on initial CT that is absent on an early follow-up qbMRI was art factual, resolved during the short follow-up interval, or was truly an occult finding on qbMRI. Larger comparative studies with longer term, systematic evaluation of clinical outcome will help to resolve some of these uncertainties. There are several potential limitations to obtaining a qbMRI in general that should be studied further. These include potential risks of MRI itself, such as device or implant contraindication or MRI-induced malfunction, burn, or projectile injury, all of which are extremely rare. Lastly, a cost analysis, which is important at most centers as MR-based imaging often costs more than CT, was not included.
This study demonstrated high sensitivity and specificity for use of qbMRI across non-shunt and non-hydrocephalic imaging indications. QbMRI has a high positive predictive value for the results of CT imaging or standard MRI, and a negative predictive value of 73%. Within trauma patients, findings not seen on qbMRI would not have impacted clinical decision-making outcome, though larger-scale studies are needed within trauma to further specify the correct clinical scenario for qbMRI use. For other non-hydrocephalic indications such as seizure or headache, qbMRI did result in some false negative findings. We observed no instance, however, of qbMRI being unable to discern an abnormality in follow-up of a previously known finding, suggesting that qbMRI may also be useful in avoiding radiation during repeat imaging taking place in a prolonged single clinical encounter. Ultimately, while qbMRI may have promise as a screening test in place of CT for specific indications, more research is needed to delineate specific clinical conditions.

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